Integrated Modeling of Cognition and the Information Environment

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Overview

- Approach
- Model Structure
  - Cognitive model
  - Physical and environmental models
- Error behavior
  - Coverage and sources
  - Answers to questions
- Work in progress/future extensions

General Approach

- Traditional cognitive modeling approaches
  - History of modeling simple, static laboratory tasks
  - Now ready to handle complex, dynamic environments
  - How?

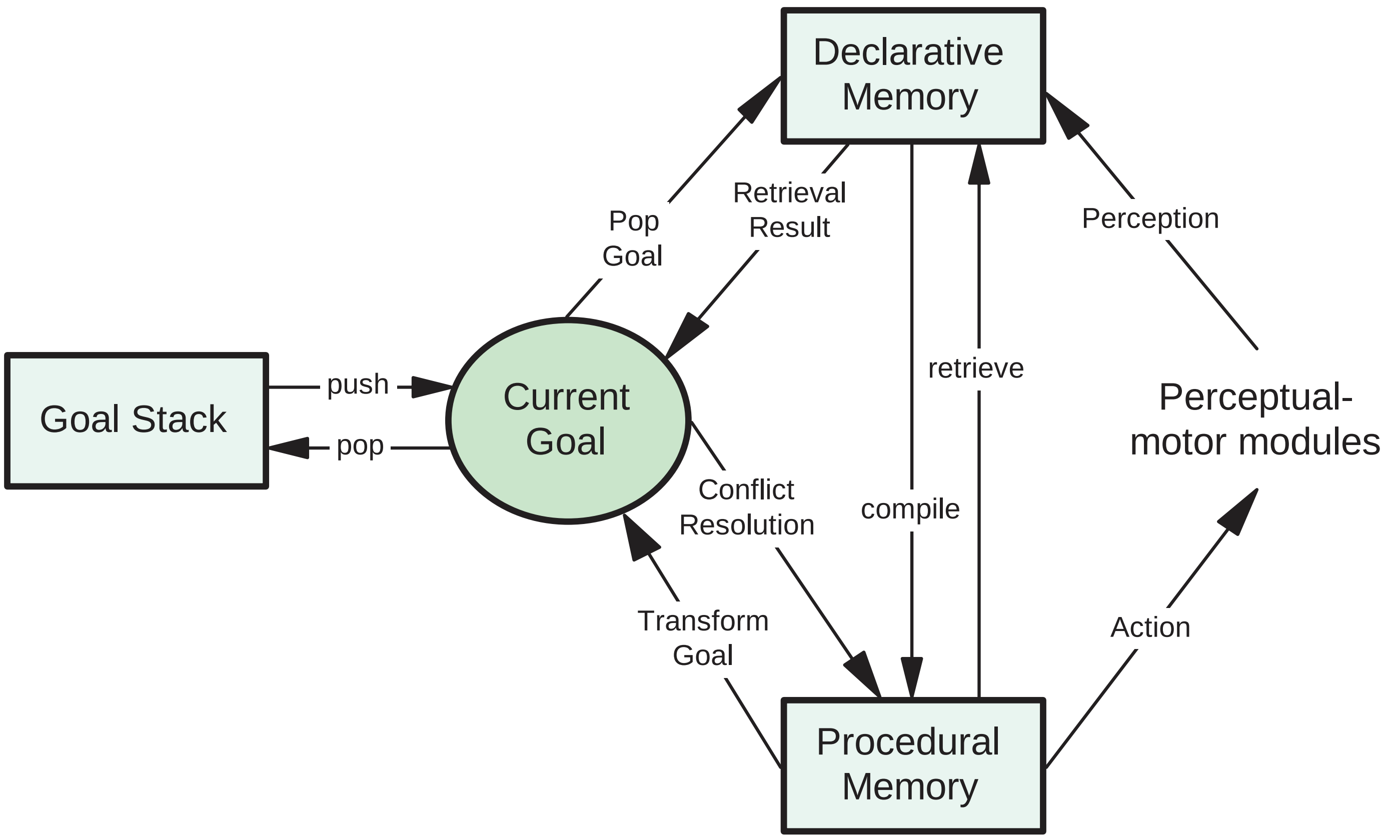
- Traditional ecological approaches
  - Good for describing task-environmental structure
  - Make simplistic assumptions about the operator

- Our goal: Unify the two approaches
  - Cognitive model informed by environmental analysis

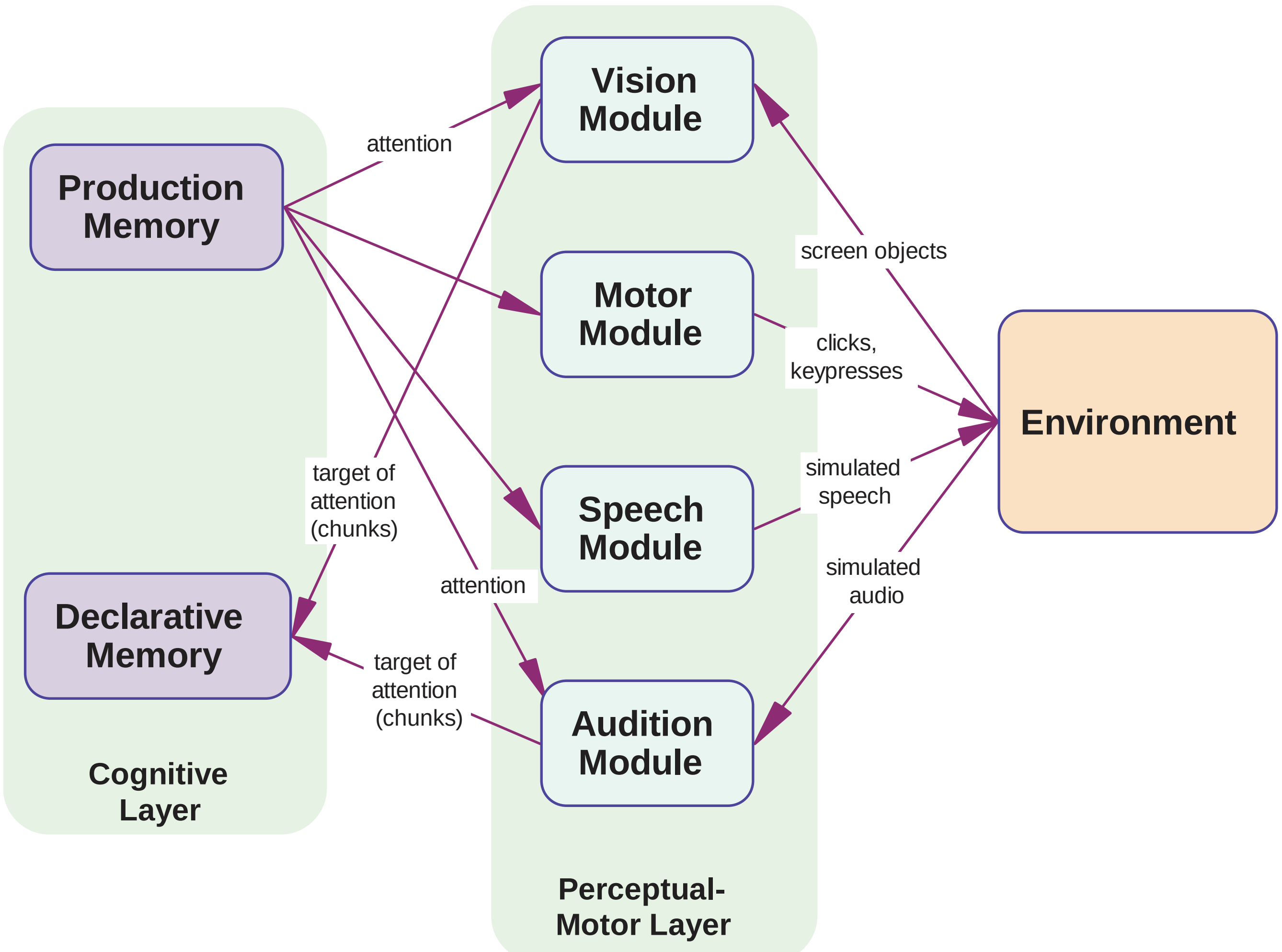
ACT-R

- ACT-R computational cognitive architecture
  - Production system
  - Semantic network
- Based on “rational analysis”
  - Activation of items in the semantic network driven by a Bayesian equation combining current system context with frequency & recency information
    - Activation determines retrieval probability and speed
  - Production selection (called “conflict resolution”) driven by equation balancing goal value, cost (in time), and success rate
- Important note: System is noisy

ACT-R


Declarative Memory
Pop Goal
Retrieval Result
Perception
Goal Stack
push
pop
Current Goal
retrieve
Perceptual-motor modules
Conflict Resolution
compile
Transform Goal
Action
Procedural Memory

ACT-R/PM


Production Memory
Declarative Memory
Cognitive Layer
Vision Module
Motor Module
Speech Module
Audition Module
Perceptual-Motor Layer
Environment
attention
target of attention (chunks)
attention
target of attention (chunks)
screen objects
clicks, keypresses
simulated speech
simulated audio

Ecological/Task Analysis

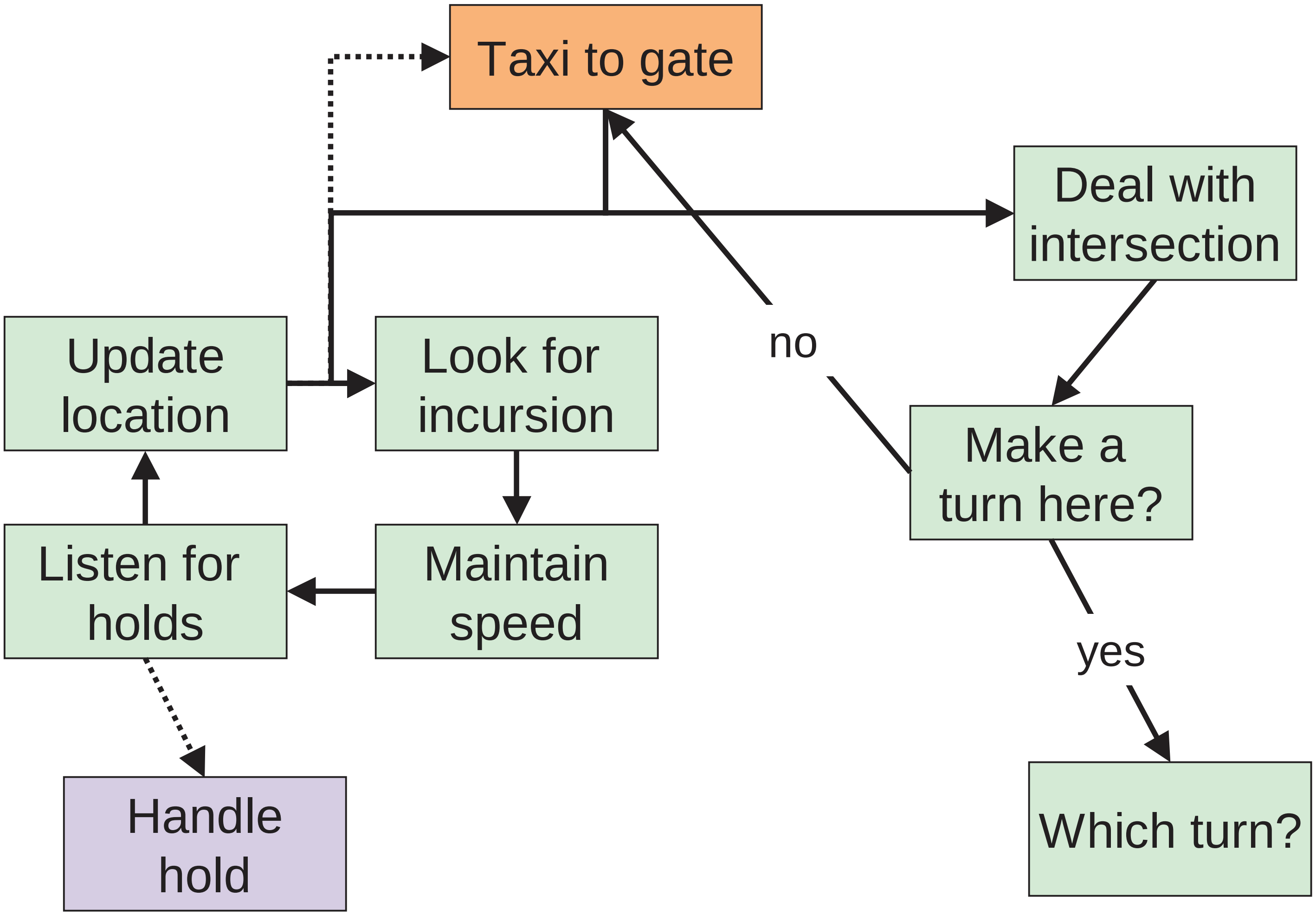
- Use environmental modeling to provide the ACT-R/PM model a realistic “external” environment
  - For example, realistic time constraints based on model of aircraft dynamics, runway layout, information layout, etc.
- Use environmental analysis (based in part on SMEs) to:
  - Identify problem-solving and decision-making strategies
  - Set parameters in ACT-R representing the information landscape for those strategies
    - Frequency and recency
    - Success rate and costs

Model Scope

- Model of single individual, the pilot, and the environment
- Currently, we do not model the FO
- Also, no model of errors resulting from miscommunications between agents
  - Not presently a major strength of ACT-R, and it appeared to us that other models could better address this
- Does not model low-level control of steering
  - Airport is a series of “rails”
  - However, steering g-force constraints respected

Focus on Adaptation and Cognitive Limits to Adaptation

Decision (Goal Selection) Flow



Maintenance Goals

- During routine (straight) taxiing, all these goals will regularly be made the focus
- When one of these goals completes, it can return information to the top goal
  - Example 1: If an incursion is detected, it will return a note to the main goal to next push a goal to handle the incursion
  - Example 2: Updating location might determine that there's an intersection coming up, which will return a note to the main goal to deal with it
- Satisfying these goals takes time

Look for Incursion

- Visual scan of scene looking for anything untoward on a rail
- Will pick up other objects that may be relevant, like new signs in view
  - If no incursion, then this will be returned to the top goal
- If there is an incursion, top goal is told so
- Top goal pushes “handle incursion” subgoal
  - Behavior would be to break as quickly as possible/necessary
  - Not actually implemented

Listen for Hold

- Very rapid in the case of no available auditory stimuli
- When such stimuli are available, listen for a few moments to determine if this is a hold issuance
- If so, return to top goal with that information
- Top goal pushes “deal with hold” subgoal

Maintain Speed

- If the model did low-level steering, this would be more inclusive
- Checks speed against standard speed bounds
- If plane is too fast, either back off throttle or apply brake
- If plane is too slow, either let up on brake or increase throttle
- Fairly rapid, but there is a little time in there to actually make the decision and to perform the relevant motor movements

Update Location

- Current location represented in a qualitative way
  - On taxiway X
  - Between taxiways Y1 and Y2
  - Heading toward Y2
- Updated primarily by reference to signs
- In a richer visual environment, this would be much more developed
  - Visual scene cues (especially in familiar airports)
  - Radio cues

Make a Turn Here?

- This can be very simple:
  - If the intersection coming up is a “T” then a turn must be made
  - Otherwise, model generally relies on memory of turns to decide whether to turn
    - Expectancies can play a role here
- This is a potential error source
  - Makeup of errors suggests that this is uncommon as a decision error, though can easily happen as a planning error

Which Turn?

- Model explicitly chooses a strategy for determining which turn to make
- Different strategies have different time demands
- Thus, model is sensitive to environmental constraints
  - Aircraft dynamics
  - Sign placement
  - Taxiway geometry
- Considers time cost and rough success rate information
  - Most accurate strategy given time available (e.g. Payne, et al.)

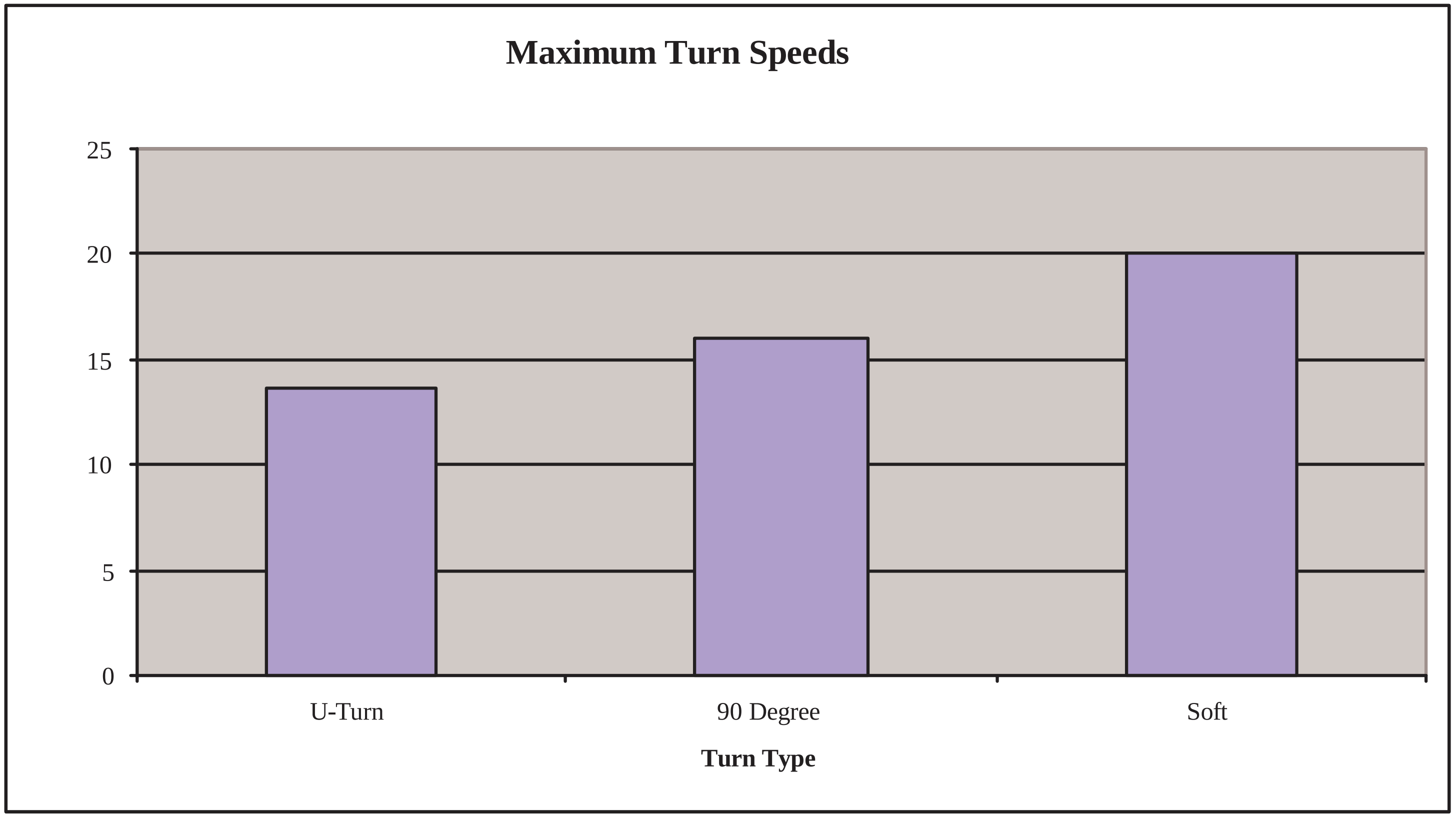
Turn Decision Strategies

- Strategies available:
  - Remember
    - Fast, increasingly inaccurate
  - Turn toward gate
    - Not quite as fast, surprisingly accurate in most airports
  - Turn which reduces larger of XY distance
    - Moderately fast, much more accurate than you'd think
  - Derive from "map knowledge"
    - Slow
    - High accuracy in principle, but still error-prone
- Buy time and re-assess (brake)

Turn Execution

- Speed in a turn is determined by
  - Turn radius (hard, 90, soft)
  - G-force limitations (guideline is 0.25 g's)
  - Model brakes a/c in time to meet speed threshold
- While we don't model the control movements made by the pilot during the turn, we assume that this requires visual guidance
  - We "lock" the visual system to the relevant yellow line during the turn

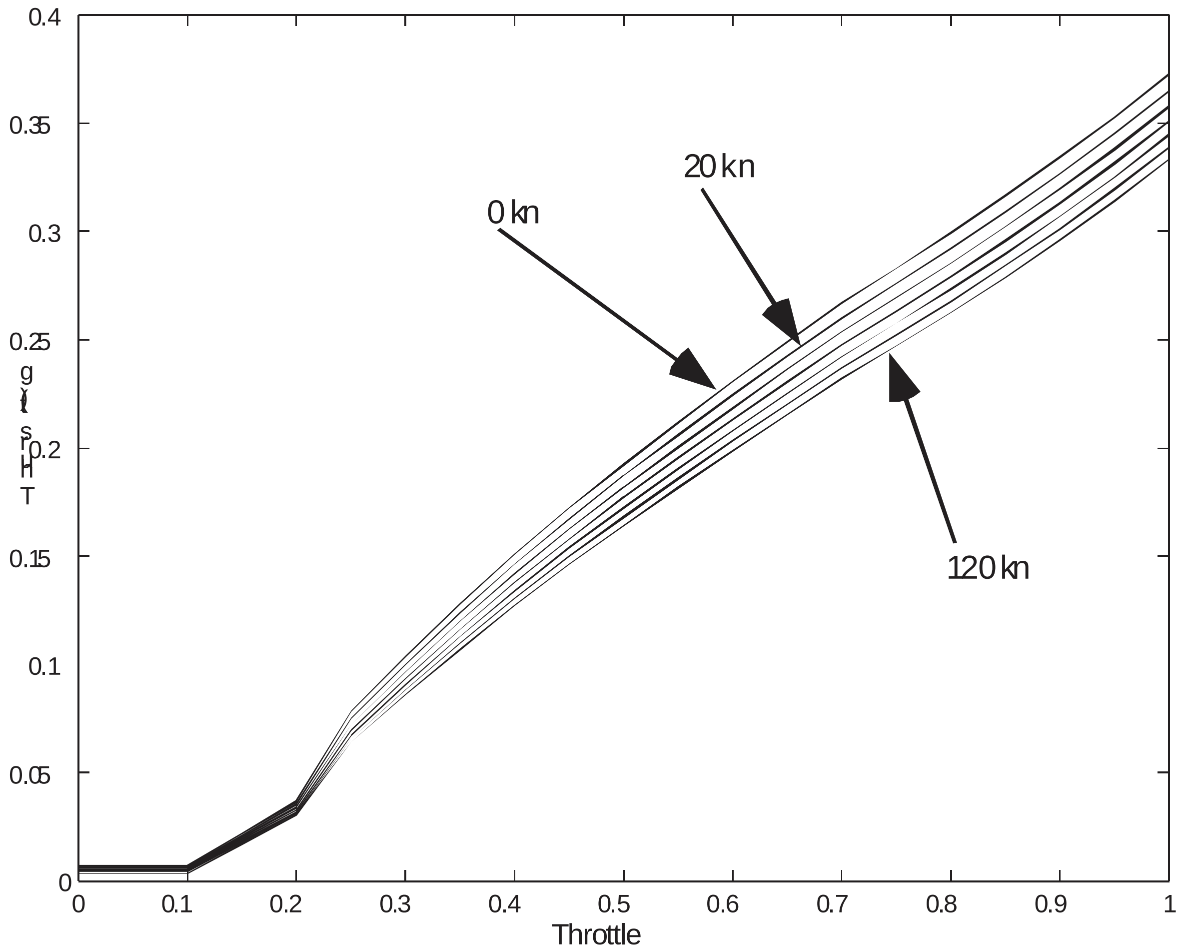
Max g Turn Analysis by Type



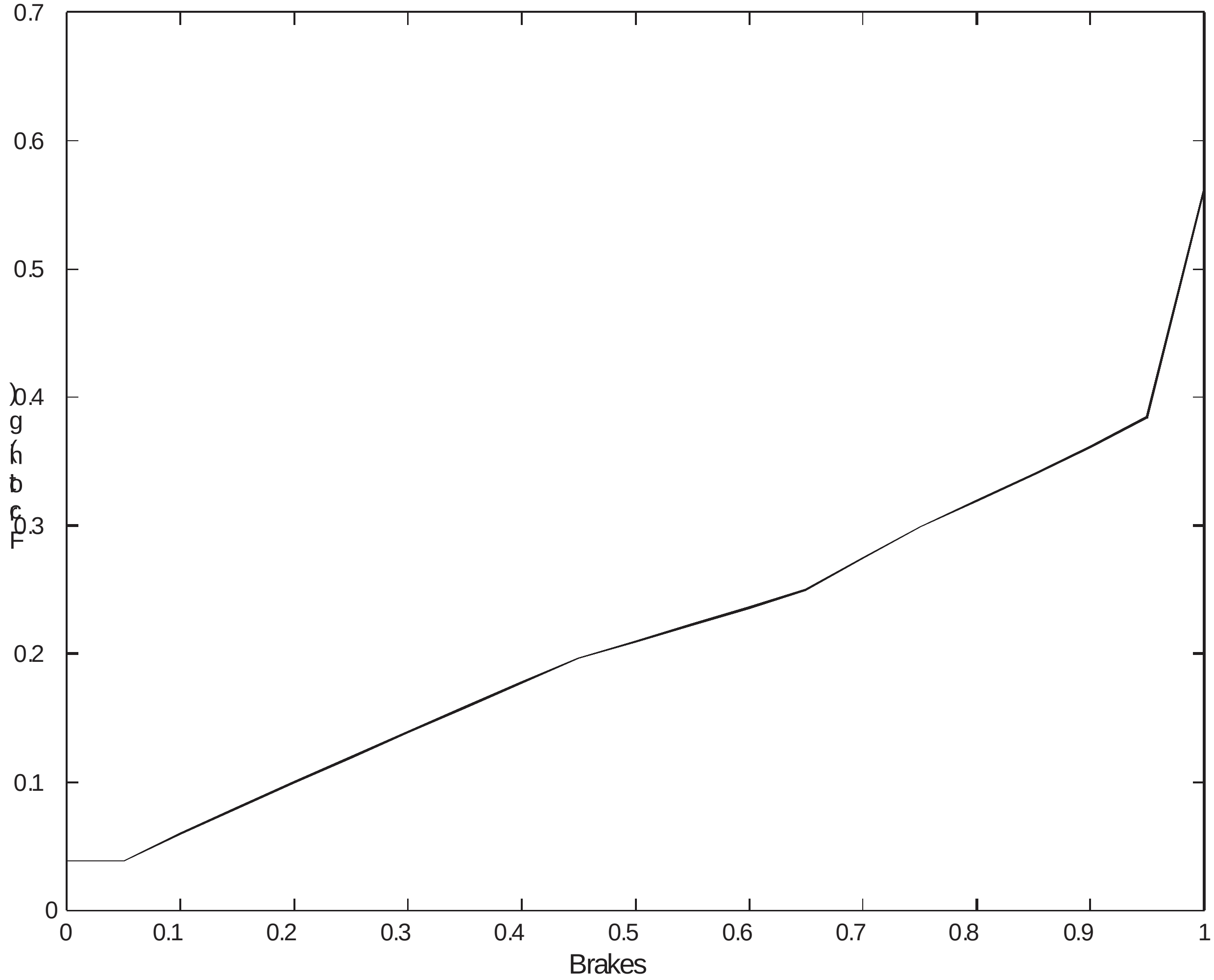
Physical Model

- Model of physical aircraft based on
  - Nissan car simulator
  - Aircraft specifications from Boeing and NASA
  - Adjustments from physics first principles
- This model determines aircraft response to
  - Thrust
  - Braking
- Time is a crucial resource to the cognitive model -- Physical model provides temporal "landscape"

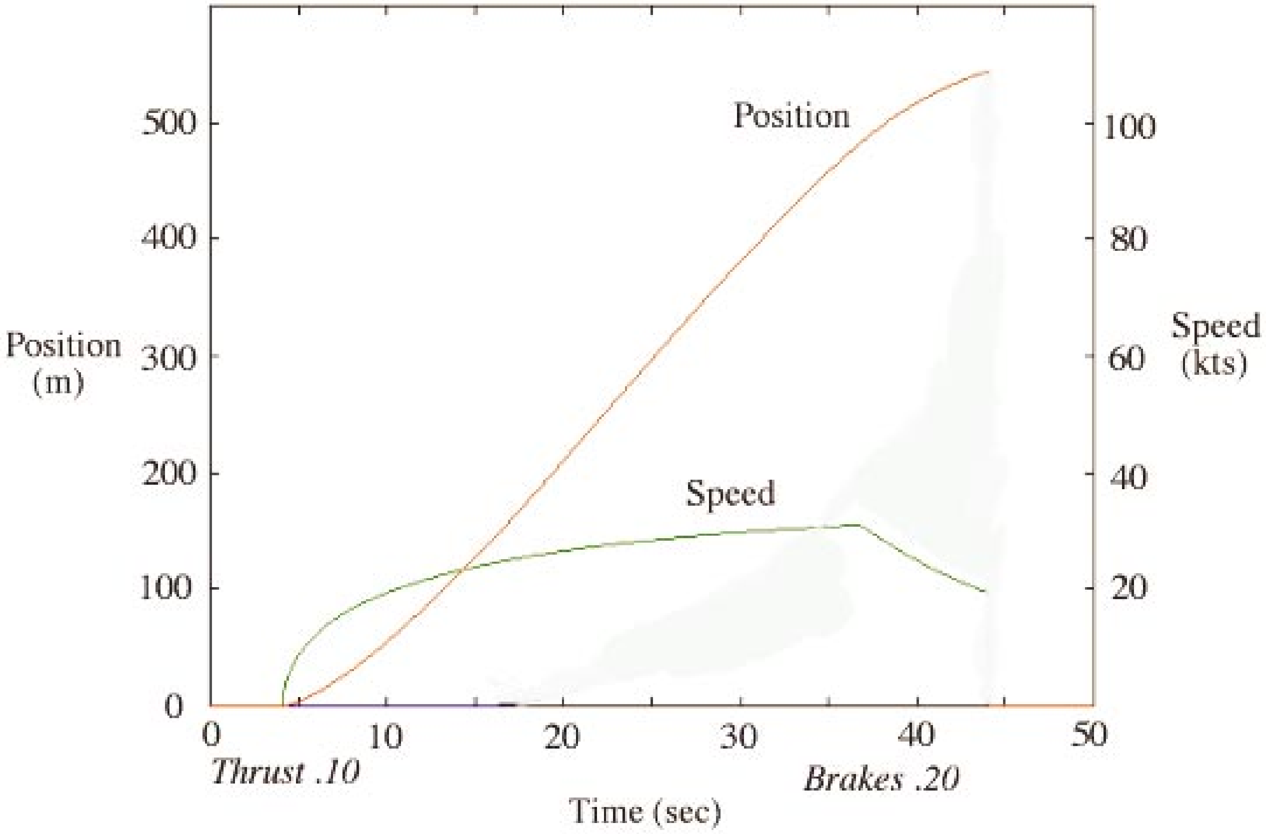
Thrust Effects -Cheng et al. 2001



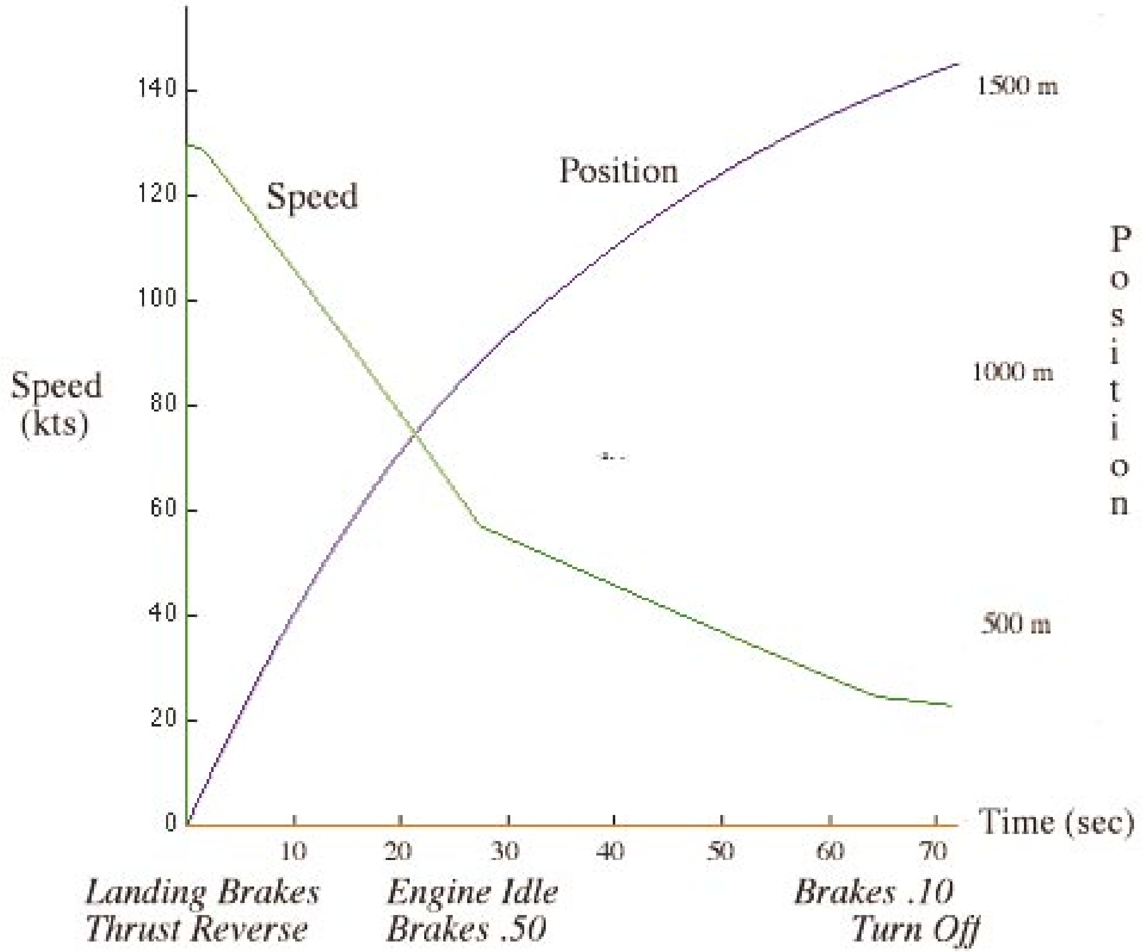
Brake Effects - Cheng et al. 2001



Aircraft Model: Start from Stop



A/C Model: Landing Timeline



Visual Environment Model

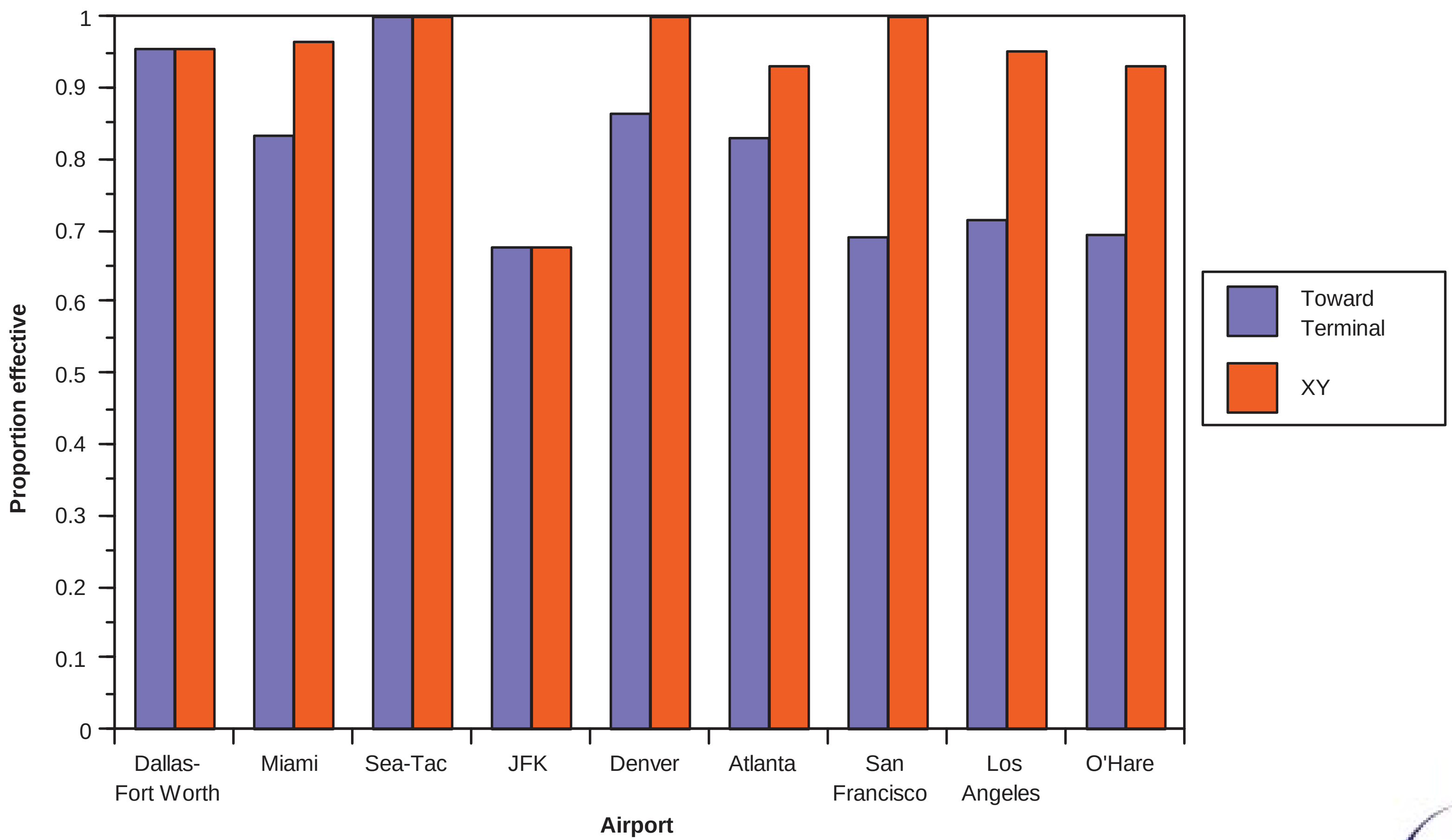
- Used the database from the NASA flight simulator
- Aircraft position and heading used to determine what objects should be visible
  - Yellow lines
  - Signs
  - Distance from each
- Work is in progress on degrading the representation of text at longer distances
  - ACT-R/PM's Vision Module contains a "best guess" mechanism for degraded input
  - This is another potential error source

Task Environment Model

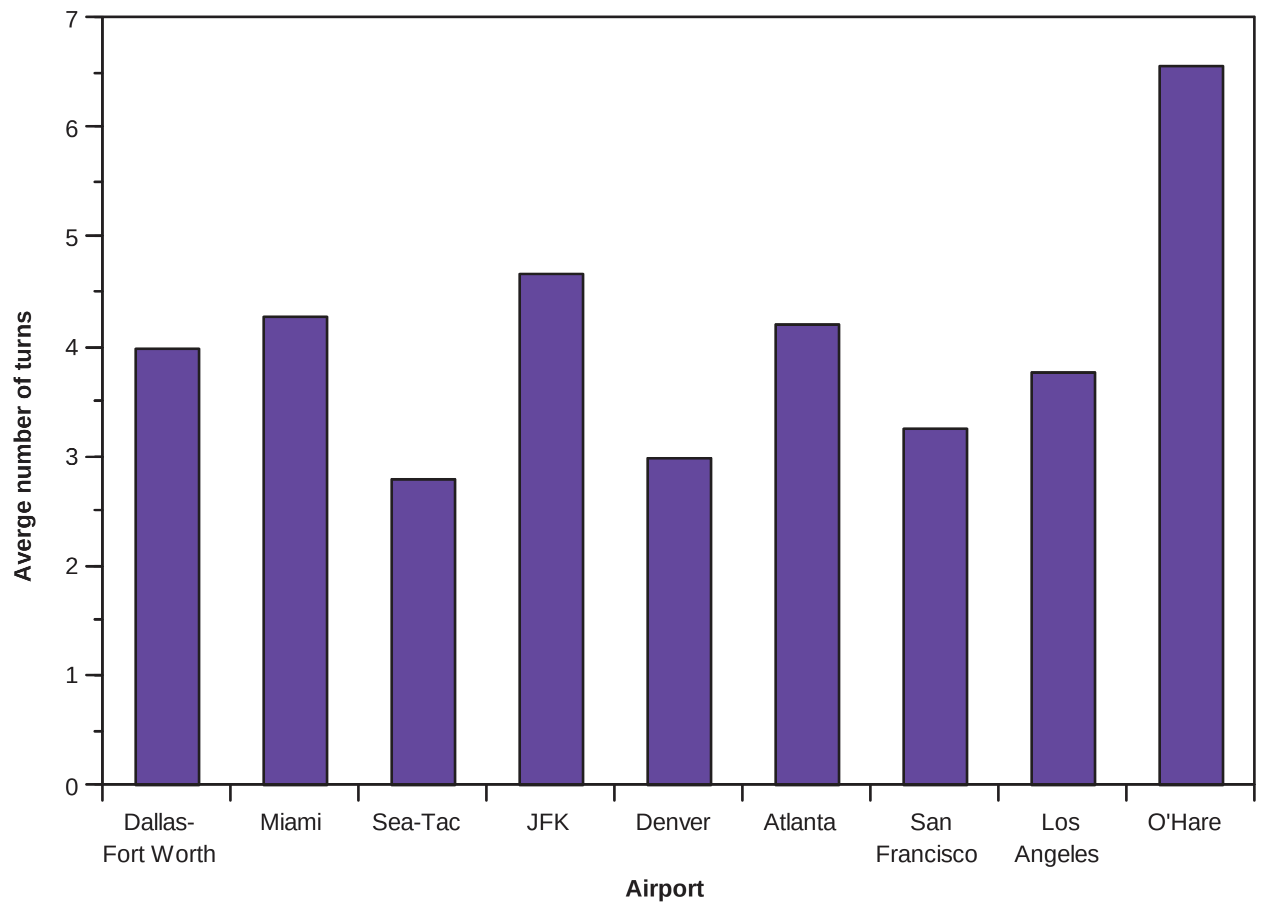
- SME provided us with Jepp charts for other airports with "nominal" taxi routes indicated. N = 284 total turns analyzed
  - Different airports
    - Near grids: Atlanta, Dallas/Ft Worth, SeaTac, Denver
    - More like O'Hare: JFK
    - In between: San Francisco, Miami, Los Angeles

- Discoveries:
  - "XY" heuristic is good across the board
  - "Toward terminal" heuristic is good many places, but not at O'Hare
  - All simulated turns at O'Hare where *both* these heuristics fail, at least one error was made ….

Heuristic Effectiveness



Average Taxi Route Length



Error Behavior

- Several sources
  - Retrieval failure/mis-retrieval
    - Exacerbated by memory-based workload
  - Use of less accurate strategies to meet time constraints
    - Exacerbated by temporal workload
  - Perceptual failures
- Coverage
  - The decision errors are at least amenable to explanation
  - Prediction is difficult
    - Need a priori basis for setting all parameters for all pilots
  - Some execution errors can be modeled

Continuing/Future Work

- Very near term
  - Monte Carlo simulations to explore parameter sensitivity
- Already mentioned
  - Degraded perceptual inputs
- Questions to answer
  - Are there other decision strategies? If so, how long do they take and how well do they work?
- Adding FO model
  - Would need more detailed information about FO tasks to help determine behavior of that model

Questions

- Is there a way to validate the conclusions from the modeling?
  - Would need more data, and more detailed data
  - Might be able to test some of the model’s tendencies better by more closely examining model’s behavior and designing studies that really test where model is most vulnerable to error
  - More time for model-building wouldn’t hurt

Other credits

- Brian Webster
- Michael Fleetwood
- Chris Fick
- NASA